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Optimization of Banana Flour Cookie Formulations Based on Physicochemical Properties

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***Abstract*: The optimisation of banana flour cookie formulations based on physicochemical properties is a multifaceted process that involves the analysis of various ingredients and their concentrations to develop a high-quality and nourishing snack. This study aimed to optimize banana flour and shortening for the best cookie formulations employing response surface methodology (RSM) in conjunction with central control rotatable design (CCRD). Thirteen different cookie formulations based on CCRD were developed. The cookies' physicochemical properties (spread ratio, density, moisture content, water activity, L value, total color difference and hardness) were determined. Regression models, response surface models, numerical optimization based on desirability function samples to determine an optimum formulation and graphical optimization by superimposing all contour plots of response surface models to visualize an optimum region were determined using a Design Expert software. The regression models could predict the physicochemical properties of cookies as a function of factors with an accuracy result depending on the responses. 60% banana flour with 58% shortening provided the desired quality of banana flour cookies. The proximate analysis result shows its quality characteristics. The optimum formulation of cookies could be used for the commercial production of banana flour cookies to develop value-added cookies with improved nutrition.**

***Keywords*: Optimization, Banana flour, Shortening, Physicochemical, RSM, Proximate.**

1. Introduction

Cookies are famous for affordability, convenience, and nutritional value (Johnson *et al.*, 2023). The main ingredients are eggs, butter, sugar, and flour. It is a crunchy, sweet dough produced with wheat flour and other common baking ingredients; the importation of wheat into Nigeria burdens the economy (Hassanally, 2020; Luparelli *et al.*, 2022a; Zungu *et al.*, 2020). Using locally grown crops to produce composite flour for cookies could be economically advantageous (Luparelli *et al.*, 2022b)

Bananas (Musa Accuminata) are a vital global crop, ranking fourth important after rice, wheat, and maize (Adeyeye, 2020). They are climacteric and have a short shelf-life post-harvest, often leading to substantial losses due to inadequate handling and rapid ripening. Processing bananas into flour can reduce these losses and enhance nutritional value. Banana flour is rich in resistant starch, aiding blood sugar control, weight management, and cholesterol reduction. It also offers minerals and vitamins. Such as potassium, sodium, Iron, Vitamin B6, Vitamin C, Phytonutrients, and fibre. Consuming green bananas has shown health benefits in conditions such as diarrhoea, insulin sensitivity, dyslipidemia, colorectal malignancy, cardiovascular disease, and celiac disease (Ahmed *et al.*, 2020; Ayo-Omogie *et al.*, 2021)

Shortening, a popular baking ingredient, enhances the texture of baked goods like cookies, cakes and pastries (Falcomer *et al.*, 2019; Sahin *et al.*, 2019; Xu *et al.*, 2020). It creates a tender, flaky texture due to its low water content, making cookies less prone to spreading (Baune *et al.*, 2022; Mitra, 2021.) Healthwise, while it is high in saturated fats, its trans-fat-free versions are available for a healthier choice, preserving the desired baking characteristics (Abiona *et al.*, 2021; Emmanuel *et al.*, 2019; Lindholm-Lehto *et al.*, 2022)

Optimizing banana flour and shortening cookie production could create value-added cookies (Abiona et al., 2021; Mitra et al.,2021.; Emmanuel et al., 2019; Evanson Inyang, 2018; YILDIZ et al., 2023). One helpful technique for improving processes and products is the Methodology of Response Surfaces (RSM). A group of statistical and mathematical methods known as response surface methodology (RSM) can examine the connections between multiple factors, or independent variables, and one or more responses, or dependent variables. (Kumar & Reji, 2023; Soares Pereira *et al.*, 2021). A literature review revealed little research on cookies made with mixtures of wheat, banana flour, and shortening using RSM (P. Mitra, 2021). To create value-added functional cookies, this study sought to optimise the ratio of spread ratio, water activity, piece density, overall color difference, desirable moisture content, and hardness while combining banana flour and shortening.

2. Materials and Methods

A. Materials

The major ingredients, mature green unripe banana flour (*Musa acuminata*) and shortening (Great value unsalted butter brand), were purchased from a local Walmart. Also, all other ingredients. The following items were bought from the Menomonie local Walmart in Wisconsin, 54751, USA: all-

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*Corresponding author: oyinloyed7118@run.edu.ng purpose flour, white sugar, brown sugar, eggs, salt (Great Value brand), baking soda (Arm & Hammer, USA), and vanilla extract (McCormick, USA).

B. Production of cookies with a value-added

Each formulation's shortening ratio to banana flour was adjusted by the central composite rotatable design (CCRD), as Table 1 illustrates. All additional substances were used in the same proportions in each of the 13 formulations. The percentage of each ingredient (banana flour plus shortening, w/w) was determined for every formulation. Using a hand-held mixer, the dry ingredients (flour, baking soda (0.5%), and salt (0.5%) were well combined. The wet components (brown sugar 6.47 per cent, butter 23.9%, and sugar 23.9%) were added and stirred until a creamy consistency was achieved. Next, the vanilla extract (0.8%) and egg (10.9%) were thoroughly mixed. The dry mix was added to the wet mix to make the cookie dough, then cut to tiny (teaspoon-sized) pieces. The little dough pieces were sheeted for baking after being put on an ungreased baking sheet. The cookie doughs were baked at 200°C for 10 minutes in an electric oven (model General Electric, USA). After baking, cookies were allowed to cool to room temperature (20°C) before being stored and subjected to additional physicochemical property study to refine and optimise a cookie recipe. The cookies were then placed in a low-density polyethene (LDPE) bag.

C. Characterizing value-added cookies in terms of quality

1) Evaluation of value-added cookies' moisture content

An oven-drying method was used to measure the moisture content of the value-added cookies (Malik et al., 2021; Mitra et al., 2020). In order to achieve a constant weight of cookies, about 5 grams of ground cookies were dried at 140°C for 2 hours. To determine the moisture content of the cookies, the weight difference between the original and dried cookie samples was used. To express it as a percentage of the starting weight, the following equation was utilised.

Two replications were done for each sample.

$$\text{Moisture content (\%)} = \frac{\text{Initial weight of cookies} - \text{Dried weight of cookies Initial}}{\text{weight of cookies}} \times 100$$

2) Evaluation of value-added cookies' water activity

The determination of the water activity of cookies was done using the Aqualab Water Activity Meter 4TEmechine (Corona, CA) and the principal ingredient as a guide. A plastic cup for water activities was filled with about five grams of ground cookies. After inserting the plastic cup into the water activity meter's sample chamber, the outer lid was shut until a consistent reading was obtained. Each sample underwent two replications, and A reported value for the average water activity was made.

3) Value-added cookie color determination

The colour profile of doughs and cookies was measured using a Hunter Lab Color flex-EZ Colorimeter (Hunter Associates Laboratory Inc., Reston, Virginia, USA). The dough and finished cookies' L value (lightness/darkness), a value (redness/greenness), and b value (yellowness/blueness) were calculated. (P. Mitra et al., 2020; Salehi, 2019; Arifin et al., 2019). The formula below was utilized to ascertain the total colour difference (ΔE):

$$Total\ Color\ Difference,\ \Delta E = \surd\ (L - L)^2 + (a - ao)^2 + (b - bo)^2$$

where the color values of the doughs were Lo, ao, and bo, and the color values of the value-added cookies were L, a, and b. Each sample underwent six color measurements, the result of which was the average value plus standard deviation.

4) Value-added cookie spread ratio calculation

AACC method 10-50D was utilised to ascertain the spread ratio of cookies (AACC, 2001). Using a Vernier Caliper, six cookies were arranged edge to edge horizontally and rotated at a 90° angle to determine the average diameter in millimetres. By rotating the cookies at different angles, the thickness of each cookie was measured five times at four different locations. The following formula was used to determine the spread ratio (Mitra et al., 2020).

$$\text{Spread ratio} = \frac{Diameter\ of\ the\ cookies\ (mm)}{Thickness\ of\ the\ cookies\ (mm)}$$

5) Calculating the value-added cookie's piece density

The value-added cookies' piece density was measured using the rapeseed displacement method (Mitra et al., 2020; Zhou et al., 2021). After being weighed, two cookies were placed in a graduated 1000 mL cylinder. After completing two sample replicates, the average cookie density was given. By tapping the cylinder repeatedly until the samples eventually settled, rapeseeds were used to fill the cylinder up to 1000 mL. After removing the cookies from the cylinder, the volume (in milliliters) was determined by deducting the volume of rapeseed from the volume of the cylinder (1000 milliliters).

$$\text{Spread ratio} = \frac{Mass\ of\ cookies(g)}{Thickness\ of\ the\ cookies\ (mm)}$$

6) Evaluating cookie hardness with extra significance

The value-added cookies' hardness (N) was measured using an Instron machine (Instron Corporation, Norwood, USA). After one cookie was placed on the lower ram and the higher ram was fastened to the cookie The cookie was crushed to an 80% strain using a 500 N load cell and a 35 mm stainless steel probe. At an 80% strain level, all the information about the sample's activity without excessive densification was available. When modifying the anvil height of the frame before the test, the specimen's total standing height was considered. For the compression test, the pre-test speed was set to 2 mm/s, the test speed to 1 mm/s, and the post-test speed to 2 mm/s. Using Blue Hill 3, the force deformation curve was produced. By maximising the force on the force-deformation curve, the hardness (N) of the cookies was ascertained (Mitra et al. 2020). The average cookie hardness value and standard deviation were determined after each sample's five replications.

D. Statistics and Modeling

1) Design experimentation

To determine the optimal formulation, the response variables (moisture content, water activity, hardness, piece density, total color difference, L value, and spread ratio) were analysed concerning the independent variables (banana flour and shortening) of the cookie dough formulations. The RSM and central composite rotatable design (CCRD) was employed. The experimental points were identified using the CCRD. There were two independent variables (factors) and five levels associated with them (coded values -1.68, -1, 0, +1, and +1.68, as indicated in Table 1). Table 1 illustrates the 13 practical points (n = 2k + 2k + m, where n = total experimental points, input variables, k = 2 and center point, m = 5 replications) that made up the experimental design (Mitra et al., 2021). These points comprised 8 factorial points, 2 axial points, and 3 replicated center points.

2) Modeling predictions and optimising cookie recipes

The correlation between the independent variables (banana flour and shortening) and response variables (moisture content, water activity, hardness, piece density, spread ratio, L value, and total color difference) of the value-added cookies was ascertained using the response surface methodology (RSM), which was also utilised to optimize the factors/independent variables on response variables (physicochemical properties of cookies). Each response variable was analysed using a second-order polynomial cubic equation as a function of the independent variables, shortening (X2) and banana flour (X1). To fit the coded variables, the following two-order polynomial cubic model was used:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_{11}X_1^2 + B_{22}X_2^2 + B_{12}X_1X_2$$

Where: Y is response variable, B_0, B_1, B_2, B_{11}, B_{22}, and B_{12} were constant also regression coefficients of the model, while X1 and X_2 were the independent variables (factors).

E. Production of Value-Added Cookies

The multi-purpose wheat flour and shortening unsalted (Great Value brand) were purchased from a local Walmart WI, USA. All other ingredients, white sugar, brown sugar, eggs, salt (Great Value brand), baking soda (Arm & Hammer, USA) and vanilla extract (McCormick, USA), were purchased from a local Walmart. Each formulation's butter and wheat flour proportions were adjusted in accordance with the central composite rotatable design (CCRD), as indicated in Table 1. All additional substances were used in the same proportions in each of the 13 formulations. For each formulation, the percentage of each additional component (butter + wheat flour) was determined. Using a hand-held mixer, the dry ingredients (45% wheat flour, 1% baking powder), and 1% salt were well combined. To attain a creamy texture, the wet ingredients (butter 20%, sugar 10%, and brown sugar 7%) were combined. Subsequently, the 15% egg and the 1% vanilla essence were added and properly combined. To make the cookie dough, the dry mix was then gradually added to the wet mix and combined. The dough was divided into tiny (teaspoon-sized) pieces. The tiny dough pieces were sheeted for baking after being put on an ungreased baking sheet. The cookie doughs were sheeted and baked in an electric oven (General Electric, USA) at 200°C for 10 minutes. After baking, cookies were allowed to cool to room temperature (20°C) before being stored and subjected to additional physicochemical property study to refine and optimize a cookie recipe. The cookies were then placed in a low-density polyethene (LDPE) bag.

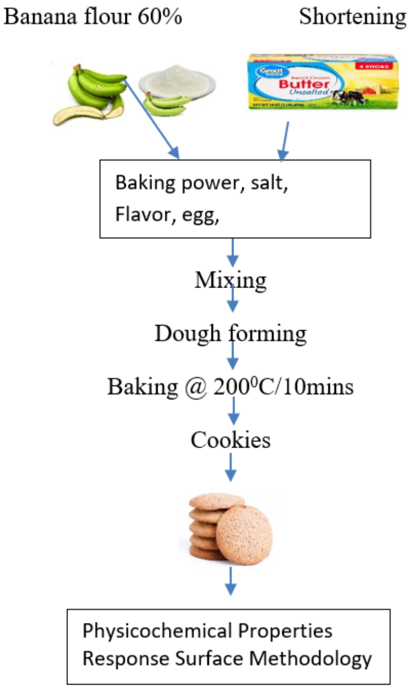

Fig. 1. Flow chart of production of cookies

3. Results and Discussion

Depending on their characteristics, the physicochemical parameters of banana flour and shortening may be predicted with an accuracy of 60% and 58% using regression models. According to the 2-dimensional response surface models, the physicochemical parameters of cookies are considerably influenced by the shortening and banana flour ($P < 0.05$). Banana flour and shortening successfully achieved the required quality of cookies through graphical and numerical optimisation.

Regression models (response prediction equations), response surface models (effect of factors when varying one and keeping the second constant), and numerical and graphical optimisation of independent variables were produced by using the Design expert program for the two-order polynomial cubic to determine the appropriate cookie formulations. The regression models were validated by the analysis of variance (ANOVA). By modelling the response as a function of one factor and holding the second constant at the center point, two two-dimensional response surface models were created. The Design-Expert program used graphical optimisation to illustrate the optimal zones. Using Design-Expert software, a trial-and-error approach based on a desirability function was used for numerical optimisation. (Mitra, et al., 2020)

Table 1
Value-added cookies' experimental design (CCRD) and results regarding moisture content, water activity, hardness, spread ratio, piece density, L value, and overall color difference

Run	**Banana flour (%) X_1**	**Shortening (%) X_2**	**Moisture content (%)**	**Water activity**	**Hardness (N)**	**Spread Ratio**	**Piece Density (g/mL)**	**L- value**	**Total color Difference**
1	(-1) 40	(+1) 70	8.62±0.00	0.51±0.00	109.88±3.92	3.20±0.01	0.72±0.00	52.95±0.12	14.60±0.46
2	(-1) 40	(-1) 50	5.99±0.00	0.39±0.00	197.18±6.99	2.63±0.09	0.83±0.04	52.95±0.12	20.62±1.32
3	(+1) 60	(-1) 50	5.62±0.00	0.35±0.01	245.83±10.75	2.82±0.05	0.84±0.05	35.69±0.35	10.11±0.60
4	(+1) 60	(+) 70	5.68±0.00	0.36±0.00	257.64±10.59	3.13±0.09	0.85±0.03	35.68±0.36	9.91±1.35
5	(0) 50	(0) 60	6.9±0.00	0.46±0.05	134.99±7.97	2.93±0.01	0.74±0.00	45.63±0.34	8.42±0.97
6	(0) 50	(0) 60	6.19±0.00	0.46±0.00	138.43±12.48	2.97±0.01	0.74±0.00	45.45±0.09	8.68±0.18
7	(0) 50	(0) 60	6.23±0.00	0.41±0.00	140.84±13.98	2.94±0.02	0.73±0.00	44.47±0.10	9.52±0.50
8	(0) 50	(0) 60	6.8±0.00	0.44±0.00	138.09±9.99	2.96±0.03	0.74±0.01	44.57±0.57	11.04±1.56
9	(0) 50	(0) 60	6.48±0.00	0.42±0.00	141.20±12.56	2.99±0.01	0.73±0.00	44.41±0.60	15.64±3.05
10	(-1.41)36	(0) 60	6.35±0.00	0.41±0.00	138.68±9.00	2.87±0.02	0.74±0.00	58.59±0.22	24.80±1.51
11	(+1.41)64	(0) 60	5.94±0.00	0.38±0.00	138.90±20	2.85±0.05	0.76±0.00	31.61±0.38	7.75±1.38
12	(0) 50	(-1.41) 46	6.78±0.00	0.43±0.00	276.20±21.08	2.42±0.02	0.87±0.00	44.27±0.01	7.68±0.15
13	(0) 50	(+1.41) 74	9.05±0.00	0.55±0.00	98.12±12.29	4.44±0.05	0.71±0.01	44.41±0.09	7.01±0.45

X1 = (B – 50)/10, X2 = (S – 60)/10, B= Banana flour (%), S= Shortening (%)

Table 2
Predictive regression models for moisture content, water activity, hardness, spread ratio, piece density, L value, and total color difference of cookies with extra value

Reaction factor		**Prediction regression models**
Moisture content (%)	=	$6.52 - 0.49x_1 + 0.74X_2 - 0.33X_1^2 + 0.56X_2^2 - 0.64X_1X_2$
Water activity	=	$0.44 - 0.028X_1 + 0.036X_2 - 0.33X_1^2 + 0.016X_2^2 - 0.025X_1X_2$
Hardness	=	$138.71 + 6.54X_1 - 58.98X_2 + 0.93X_1^2 + 25.11X_2^2 - 11.33X_1X_2$
Piece density	=	$0.74 + 0.023X_1 - 0.041X_2 + 0.019X_1^2 + 0.036X_2^2 + 0.030X_1X_2$
Spread ratio	=	$2.96 + 0.015X_1 + 0.53X_2 - 0.085X_1^2 + 0.23X_2^2 - 0.092X_1X_2$
L value	=	$44.95 - 8.00X_1 + 0.43X_2 - 1.14X_1^2 - 0.022X_2^2 + 0.038X_1X_2$
Total color difference	=	$10.66 - 4.92X_1 - 0.90X_2 + 3.31X_1^2 - 1.16X_2^2 + 1.46X_1X_2$

The variance analysis. The created regression models for the moisture content, water activity, hardness, spread ratio, piece density, L value, and overall color difference of the cookies were validated by ANOVA.

As indicated in Table 1, thirteen distinct formulations of value-added cookies were created by adjusting the amounts of shortening and banana flour by the CCRD experimental conditions and physicochemical properties of the cookies. Table 1 displays the measurements of many parameters, such as moisture content, water activity, hardness, spread ratio, piece density, L value, and overall color difference. The moisture content (9.05-5.62%), water activity (0.55-0.35), hardness (296.20-98.12 N), spread ratio (4.44-2.42), piece density (0.87-0.71 g/mL), L value (58.59-35.68) and total color difference (24.80-7.41), and of cookies changed depending on how the cookie dough was made. Still, there was a difference in the variability of those cookie qualities. The findings showed that adding shortening and bananas to cookies substantially impacted their physicochemical characteristics ($p < 0.05$). The L-value (lightness) of the value-added cookies dropped as the amount of banana flour increased. As more banana flour was added, the cookies got darker. The physicochemical parameters of value-added cookies yielded results consistent with previous research. (Arifin *et al.,* 2019; P. Mitra *et al*., 2020; Salehi, 2019; Zhou *et al*., 2021)

For each formulation of cookies created with a shortening and banana flour combination, the water activity was more than 0.6 (on the set water activity of microbial growth) (Table 1). Under 0.6 water activity, the value-added produced cookies were shelf stable and could be kept longer at room temperature. Due to a lack of available water, microorganisms cannot grow under 0.6 water activity of food goods. (Barbosa-Canovas *et al.,* 2021; Morasi *et al.,* 2022) A second-order polynomial cubic equation was fitted with the experimental results (Table 1) of the physicochemical properties of cookies to develop regression models to predict the physicochemical properties (response variables) of cookies as a function of independent variables (factors) of banana flour (X) and shortening (XA). The second-order polynomial cubic equation's coefficients and constants were discovered by integrating the CCRD with response surface methodology (RSM) and Design Expert software. The backward method eliminated the useless terms from the second-order polynomial equation. Table 2 shows regression prediction models as a function of coded independent factors for value-added cookies' physicochemical properties (response variables).

Table 3 displays the ANOVA findings for the cookies' response variables. Every response variable had a p-value of less than or equal to 0.05. The p-value results showed that in contrast to research by (Mitra et al. 2020; Salehi, 2019; Zhou et al., 2021), each factor in the regression models substantially impacted the response variables (physicochemical attributes of cookies). Except for the overall colour difference, each response variable had an F value more significant than the one at a critical point (F-critical). Table 3 shows that the value-added cookies' real color difference had a more significant F value (7.47) than that at a vital time (4.74). The response variables' F values exceeded the F value at a crucial moment,

Table 3
ANOVA for the moisture content regression models, hardness, water activity, piece density, spread ratio, L value, and the total color of value-added cookies

Modelling Source	Sum of Square	DF	Mean Square	F-Value	F critical	P Value	Adequate precision.	R^2
Moisture content	11.20	5	2.24	7.86	3.10	0.00	9.65	0.84
Water activity	0.029	5	5.77	4.49	3.49	0.03	7.61	0.76
Hardness	33107	5	6621	90.70	2.99	0.00	29.52	0.98
Piece Density	0.032	5	6.33	7.25	2.37	0.01	8.40	0.83
Spread ratio	2.71	5	0.54	4.75	2.30	0.03	7.37	0.77
L-value	521.66	5	104.33	110.21	2.99	0.00	34.25	0.98
Total color dif.	302.07	5	60.41	7.47	4.74	0.01	8.87	0.84

Table 4
The desirability function of value-added cookies was used to optimise numerically

Parameter	Band	Least limit	highest limit	Lower limit	Upper weight	Importance
Banana flour	Maximum	40	60	1	1	3
Shortening	Minimize	50	70	1	1	3
Moisture content	Minimize	5.62	9.05	1	1	3
Water activity	Minimize	0.35	0.55	1	1	3
Hardness	Minimize	98.12	276.2	1	1	3
Density	Minimize	0.71	0.87	1	1	3
Spread ratio	Minimize	2.38	4.69	1	1	3
L-value	is in range	31.61	52.95	1	1	3
The total colour dif	is in the range	of 7.01,	24.8	1	1	3

SOLUTION

N/S	**Banana Flour %**	**Shortening %**	**Moisture content**	**water activity**	**Hardness N**	**Piece Density**	**Spread ratio**	**Total Value**	**Color dif**	**Desirability**
1	**60.00**	**57.94**	**5.71**	**0.38**	**161.72**	**0.78**	**2.81**	**35.79**	**0.89**	**0.762**
2	**60.00**	**58.40**	**5.71**	**0.38**	**158.03**	**0.78**	**2.42**	**35.75**	**0.93**	**0.761**

leading to the rejection of the null hypothesis. The regression models' higher F values showed they could significantly predict response variables. (Mitra *et al.,* 2020)

All the response variables had adequate precision values greater than 7 (Table 3), which the Design Expert program said showed sufficient model discrimination. Mitra et al. (2020) recommended that the precision is good. Because the appropriate precision measured the range of the predicted values at a design point to the average prediction error, a precision higher than 7 demonstrated one of the proper signals of the accuracy of the model for the prediction of response variables (physicochemical properties of value-added cookies) (Mitra, 2021; Mitra et al., 2020) As recommended by (Mitra et al., 2020), the coefficient of determination (R2) value varies from 0 to 1, with a score closer to 1 is better. The moisture content, water activity, hardness, piece density, spread ratio, L value, and overall color difference of the value-added cookies had R2 values that were almost equal to 1. However, Table 3 demonstrates that the spread ratio and water activity of the cookies had R2 values of 0.77 and 0.76, respectively. The lower R2 of the spread ratio and water activity models did not prevent the regression models from accurately predicting the two cookie properties. This was due to their more significant p-value and more muscular sufficient precision of 7.61 and 7.37, respectively (Yildizet et al., 2023). The ANOVA analysis (Table 3) led to the conclusion that the value-added cookie response variables' cubic regression models agreed with the experimental findings regarding forecasting the value-added cookie's physicochemical characteristics as a function of shortening and banana flour.

A. Factors influencing responses in response surface modelling

The response surface models help explain how value-added cookies' variables (banana flour and shortening) affect the responses (moisture content, water activity, hardness, piece density, spread ratio L value, and overall color difference). Two-dimensional graphs created by changing one element while holding the other constant for a response helped visualize the link between the components and responses. Response surface diagrams showed how the independent variables (factors) changed about the response variables (the physicochemical characteristics of cookies). Figure 2 displays the graphs of the response surfaces. For every answer, the response surface models generated 2-dimensional graphs that indicated the effects of both shortening and banana flour

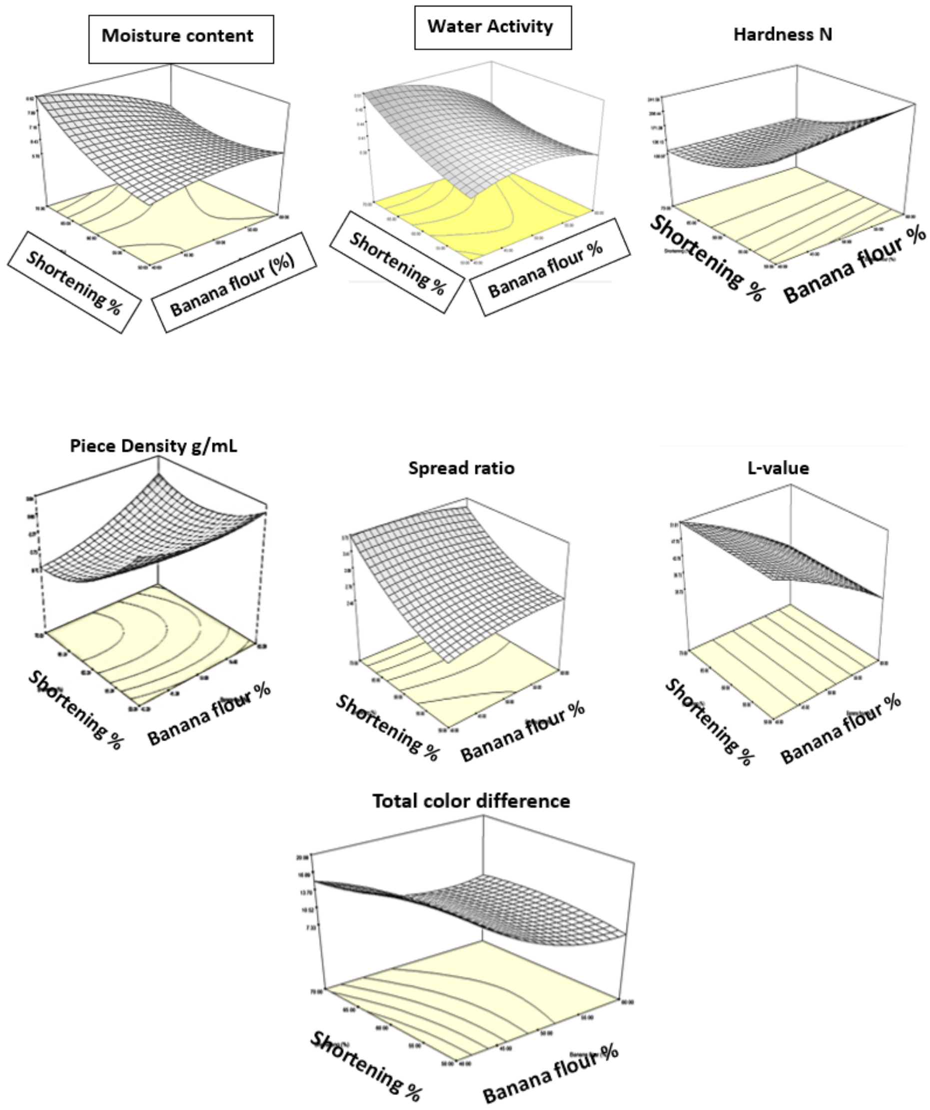

Fig. 2.

together, and the impact of banana flour was kept constant about shortening. Concerning the moisture content, total color difference, spread ratio, piece density, and hardness as response parameters for the value-added manufactured cookies. The banana flour had a negative linear effect on moisture content and water activity, a mild quadratic effect on overall color difference and L value, and a linear influence on spread ratio, piece density, and hardness in the value-added cookies (Figure 2).

The results showed that adding 60% more banana flour to the cookies reduced the moisture content and water activity to 5.62% and 0.35%, respectively, and enhanced the value-added produced cookies' spread ratio, piece density, and hardness to 4.44, 0.87, and 276.20.

With up to 50% banana flour, the overall colour difference of the cookies marginally diminished, while with less banana flour, it increased. Banana flour's smaller particle size may result in insufficient capacity to hold water. The created cookies' moisture content rose due to the increased shortening. At first, the dark hue of the banana flour may contribute to a minor increase in the overall colour variation of the cookies. Additionally, because of Millard reactions, starches' dextrinisation, and sugars' caramelisation, enhanced banana flour developed a black colour during baking at high temperatures (Godswill et al., 2019; Jan et al., 2021). This phenomenon may be responsible for the banana flour's quadratic effect on the overall colour variation of the produced cookies.

The quality and packaging design of cookies depend heavily on their spread ratio. The viscosity of the cookie batter affects the spread ratio. The anti-plasticizing and shortening properties of sugar influence the dough's viscosity and the gluten proteins' cross-linking during baking. The amount of starch gelatinization is limited by the doughs' high sugar concentration and low moisture level. Cookies are created with a noncontinuous structural network made of shortening granules, proteins, and non-gelatinized starches.. This could be why the value-added set cookies' higher spread ratio when shortening increases. The results agreed with other studies (Abdullahi, 2021; Bhat et al., 2020). Compaction and a decrease in porosity may result from the cultivated banana flour's decreased moisture content in the value-added cookies. As a result, adding banana flour to value-added cookies enhanced their piece density.

Its hardness is the most important textural characteristic for determining a food product's quality. According to Mitra et al. (2020) and Sahu & Patel (2021a), the products' hardness is inversely correlated with their moisture content and linearly correlated with their density. The value-added cookies' increased piece density and lower moisture content could make them more durable than cookies made with banana flour. High-temperature baking may alter the banana flour's ability to hold water, increasing the amount of water lost when baking with grown banana flour (Khoozani et al., 2020a; Sahu & Patel, 2021b). This could be the effect of value-added cookies having less moisture due to an increased percentage of banana flour in the cookies. The overall colour difference during baking was impacted by the brown colour of the banana flour. This could be the reason for the cookies' increased actual colour variation in the banana flour. (Sahu & Patel, 2021b; Khoozani et al., 2020b). This phenomena could account for the increased spread ratio of cookies baked with pumpkin flour, as well as the reason why some cookie recipes call for shortening.

Due to a correlation between piece density and food product hardness, the piece density of the cookies followed a similar pattern (quadratic) as the hardness of the cookies (Sahu & Patel, 2021a). According to Jan et al. (2021) and Abdullahi Momohjimoh Bello (2021), the results corroborated. With more shortening, the value-added cookies had a higher moisture content.

An analysis of Figure 2. Effect of shortening and banana flour percentages on value-added cookies' moisture content, water activity, hardness, spread ratio, piece density, L value, and overall color variation.

B. Formulation optimisation for value-added cookies

1) A desirability function is used in numerical optimization

A desirability function was used to numerically Optimize the value-added. The pieces density, hardness, spread ratio, moisture content, L value, and water activity of cookies as response variables. Using a mathematical approach, the desirability of cookies was determined by combining all answer variables into a single response (Mitra et al., 2020). The study aimed to maximize banana flour and minimize shortening by minimizing moisture content, water activity, overall color difference, piece density, and hardness; to obtain a L value and spread ratio within range; and to maximize overall color difference. The geometric mean determines the desirability function, which ranges from 0 to 1. A mean value around 1 indicates the highest desirability. Multiple trials were conducted to identify the ideal circumstances. The ultimate perfect state was reached when shortening was reduced, and banana flour was optimised. To enhance the value addition in terms of nutrition and economy, we considered using the maximum amount of banana flour in the cookies. Table 4 displays the two optimal solutions (determined by a desirability rating) after comparing all trial tests. Table 4 indicates that the second solution (desirability = 0.82) provided the best conditions for producing value-added cookies of a desirable calibre. With desirability of 0.76, the ideal formulation had banana flour (60%) and shortening (57.94%), according to the best results (Table 4). The perfect cookie formulation had the following characteristics: piece density (0.78g/mL), moisture content (5.71%), water activity (0.38), L value (35.71), the overall color difference (0.89), spread ratio (2.81), and hardness (161.72 N).

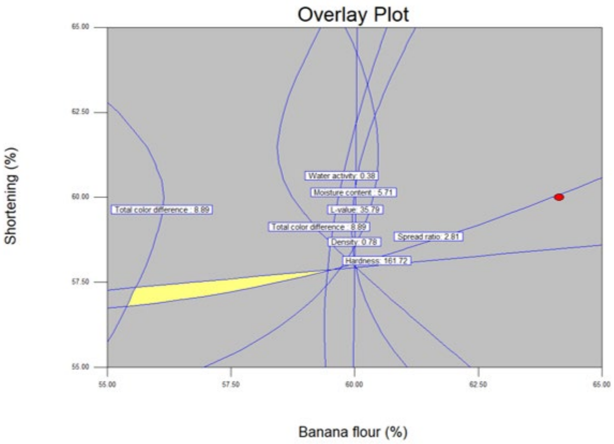

Fig. 3.

The figure 3 displays the graphic optimisation (shaded area) of the value-added cookies' moisture content, water activity, hardness, spread ratio, piece density, L value, and overall color difference.

2) Utilizing response variable contour overlays for graphic optimisation

By combining numerical optimisation with graphical optimisation, a significant understanding may be built to identify the optimal region of the cookie recipes. A graphic representation of the numerically optimised solution (Table 4) was created to identify the optimal regions where all criteria were satisfied. All response variables, including moisture content, water activity, hardness piece density, spread ratio L value, and overall color difference, were plotted as contours and superimposed as functions of two variables, shortening and banana flour, with the other variable held constant at the centre. The darker areas in the superimposed plots, or optimal zones, were visualized as depicted in Figure 3 (Mitra et al., 2020). Figure 3's contour plots of all response variables with shaded regions revealed that 57.94% shortening and 60% banana flour was the ideal range.

4. Conclusion

In conclusion, optimising banana flour cookie formulations, particularly at the 60% banana flour level, emerges as a promising avenue for utilising indigenous crops over foreign wheat flour. The physicochemical properties analysed in this study underscore the viability of producing cookies with a substantial banana flour content. Notably, these banana flour cookies exhibit elevated levels of fibre and resistant starch, contributing to their potential health benefits. Incorporating such cookies into dietary choices could significantly ameliorate nutritional diseases, including diabetes, reduce weight, and regulate high blood pressure. By harnessing the nutritional advantages of banana flour, this research offers a locally sourced alternative to wheat flour, promotes sustainable practices, and addresses health concerns by developing functional food products. The 60% banana flour formulation is a valuable and health-conscious option in cookie production.

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